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from a water surface, and it is natural to interpret the mirage as evidence of a body of water.

Sometimes a warm layer of air can be trapped between layers of cooler air overhead (a temperature inversion) resulting in light-ray paths that curve downward, so that distorted images of ships or land that normally would lie hidden below the horizon can be seen (see Fig. 2). *SEE METEOROLOGICAL OPTICS; REFRACTION OF WAVES; TEMPERATURE INVERSION.*

Robert Greenler

Mirror optics

The use of plane or curved reflecting surfaces for the purpose of reverting, directing, or forming images. The most familiar use of reflecting optical surfaces is for the examination of one's own reflected image in a flat or plane mirror. A single reflection in a flat mirror produces a virtual image which is reverted or reversed in appearance. The use of one or more reflecting surfaces permits light or images to be directed around obstacles, with each successive reflection producing a reversal of the image. A curved mirror, either spher-

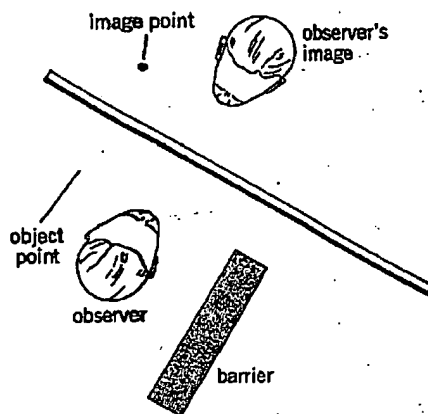


Fig. 1. Formation of images by a plane mirror.

ical or conic in form, will produce a real or virtual image in much the same manner as a lens, but generally with reduced aberrations. There will be no chromatic aberrations since the law of reflection is independent of the color or wavelength of the incident light. *SEE ABERRATION (OPTICS); OPTICAL IMAGE.*

An optical surface which specularly reflects the largest fraction of the incident light is called a reflecting surface. Such surfaces are commonly fabricated by polishing of glass, metal, or plastic substrates, and then coating the surface of the substrate with a thin layer of metal, which may be covered in addition by a single or multiple layers of thin dielectric films. The law of reflection states that the incident and reflected rays will lie in the plane containing the local normal to the reflecting surface and that the angle of the reflected ray from the normal will be equal to the angle of the incident ray from the normal. This law is a special case of the law of refraction in that the angles rather than the sines of the angles of incidence and reflection are equal. Formally, this relation is com-

monly used in calculations by setting the effective index of refraction prior to incidence on the surface. When this concept is introduced, all of the formulas relating to lenses are applicable to reflective optics. In this article, however, the imaging relations will be described in the most appropriate form for reflecting surfaces. *SEE GEOMETRICAL OPTICS.*

Plane mirrors. The formation of images in the plane mirrors is easily understood by applying the law of reflection. Figure 1 illustrates the formation of the image of a point formed by a plane mirror. Each of the reflected rays appears to come from a point image located a distance behind the mirror equal to the distance of the object point in front of the mirror. In Fig. 1, the face of the observer can be considered as a set of points, each of which is imaged by the plane mirror. Since the observer is viewing the facial image from the object side of the mirror, the face will appear to be reversed left for right in the virtual image formed by the mirror. Such a virtual image cannot, of course, be projected on a screen, but can be viewed by a lens, in this case the eyes of the observer. Figure 1 also indicates the redirection of light by a plane mirror, in that a viewer who cannot observe the object point directly can observe the virtual image of the point formed by the mirror. A simple optical device which is based on this principle is the simple mirror periscope (Fig. 2), which uses two mirrors to permit viewing of scenes around an obstacle. In this case two reflections are present and provide an image which is correctly oriented, and not reverted, to the observer. The property of reversion in a complicated mirror system depends upon the location and view direction of the observer, as well as the number of reflections that take place and the orientation of the planes through which the light is directed. *SEE PERISCOPE.*

Prisms. These are solid-glass optical components that use reflection at the faces to provide redirection of the optical pencils passing through them. The advantage of the use of a prism is that the reflecting surfaces are maintained in accurate location with respect to each other by the integrity of the glass material making up the body of the prism. Difficulties with prisms are that very homogeneous glass is required since the light may make many passes through the prism, and that a prism is optically equivalent to insertion of a long block of glass into the imaging system. The insertion of such a glass block often results in a system which is mechanically shorter in space, but the aberration balance of the imaging system is changed, frequently requiring a redesign of the



Fig. 2. Simple mirror periscope.

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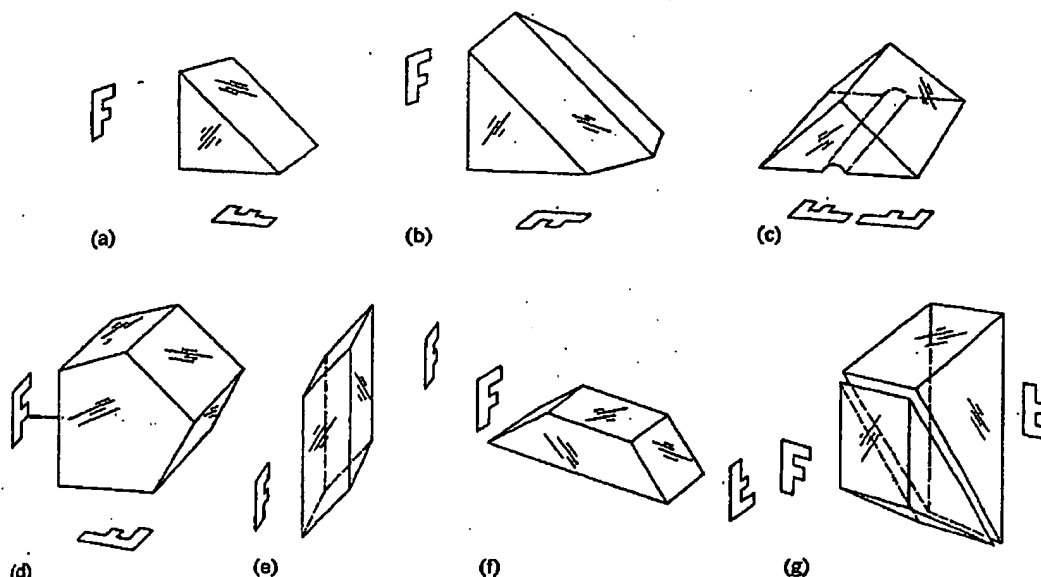


Fig. 3. Prism types. (a) Right-angle. (b) Amici roof. (c) Porro. (d) Pentaprism. (e) Rhomboid. (f) Dove. (g) Pechan.

associated optical components in order to accommodate the increased glass path. It is obvious that the use of solid glass prisms may introduce more weight into the optical design than the equivalent metal mounts required for a similar arrangement of mirrors in air. In certain cases, the angle of incidence on a reflecting surface within the prism may exceed the critical angle of incidence, and no reflective coating may be required on such a surface. Figure 3 shows some common types of optical prisms with reflecting surfaces. The applications of such prisms range from simple redirection of light to variable angle of rotation of the image passed through the prism and binocular combination of images. A special case of reflection is the use of a beam splitter which permits the splitting of light, or the combining of two beams by the use of a surface which is partially reflecting and partially transmitting. *SEE BINOCULARS; OPTICAL PRISM.*

Spherical mirrors. These are reflecting components that are used in forming images. The optics of such mirrors are almost identical to the properties of lenses, with their ability to form real and virtual images. In the case of spherical mirrors, there is a reversal of the direction of light at the mirror so that real images are formed on the same side of the mirror as the object, while virtual images are viewed from the object side but appear to exist on the opposite side of the mirror. Both concave and convex spherical mirrors are commonly encountered. Only a virtual erect image of a real object will be formed by a convex mirror. Such mirrors are commonly used as wide-angle rearview mirrors in automobiles or on trucks. The image formed appears behind the mirror and is greatly compressed in space, with a demagnification dependent on the curvature of the mirror. A concave spherical mirror can form either real or virtual images. The virtual image will appear to the observer as erect and magnified. A common application is the magnifying shaving mirror frequently found in bathrooms. A real image will be inverted, as is the real image formed by a lens, and will actually appear in space between the observer and the mirror.

Figure 4 shows the formation of real and virtual images by a spherical mirror. The equation which ap-

plies to all of the image relations is given below. The

$$\frac{1}{S'} + \frac{1}{S} = \frac{2}{R}$$

distances S and S' are measured from the surface of the spherical mirror; when either is negative, a virtual image is formed behind the mirror. The constant R is the radius of curvature of the mirror. The magnification of the image is the ratio of the image distance S' to the object distance S .

Conic mirrors. These are a special case of the spherical mirror with improved image quality. A spherical mirror will form an image which is not perfect, except for particular conjugate distances. The use of a mirror which has the shape of a rotated conic

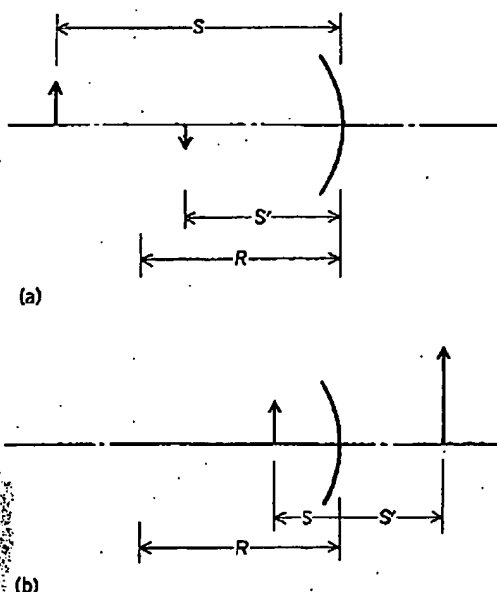


Fig. 4. Formation of images by spherical mirror. (a) Real image. (b) Virtual image.

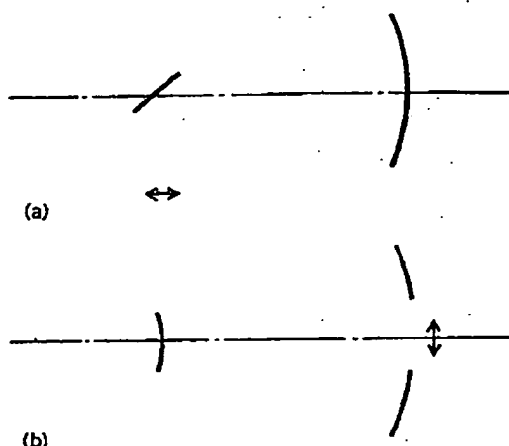


Fig. 5. Applications of conic mirrors. (a) Newtonian telescope. (b) Cassegrain telescope.

section, such as a parabola, ellipsoid, or hyperboloid, will form a perfect image for a particular set of object-image conjugate distances and will have reduced aberrations for some range of conjugate relations. Two of the most familiar applications for conic mirrors are shown in Fig. 5. Figure 5a shows the use of a paraboloid of revolution about the optical axis to form the image of an object at an infinite distance. In this drawing the image to be viewed by the observer at the eyepiece is relayed to the side of the telescope tube by a flat folding mirror in what is called a newtonian form of a telescope. This demonstrates one of the difficulties that is found with the use of reflecting optical components to form real images; namely, that the image must often be relayed out of the incident path on the image-forming mirror, otherwise the observer will block some of the light from the object. Not all reflecting systems carry out this relaying in the same manner. The Cassegrain system uses a curved secondary mirror to achieve magnification of the final image while allowing the image to fall outside the telescope barrel.

Figure 5b shows the use of a paraboloid as the primary mirror with the image relayed to the final image location by a hyperbolic secondary mirror. Such a use of two mirrors permits the construction of a long-focal-length telescope within a relatively short space. This latter form, usually referred to as a Cassegrain telescope, serves as the principal type of modern reflecting astronomical telescope. One of the advantages of this type of telescope design is the freedom from chromatic aberration that would be present in a refracting telescope. *SEE OPTICAL SURFACES; OPTICAL TELESCOPE.*

Mirror coatings. The reflectivity of a mirror depends on the material used for coating the reflecting surface. The conventional coatings for glass mirror surfaces are silver or aluminum, which are vacuum-deposited or sputtered onto the surface. In some cases, chemical deposition will be used. Most mirrors intended for noncritical uses, such as looking glasses or wall mirrors, will have the reflecting metallic coating placed on the back side of the glass, thus using the glass to protect the coating from oxidation by the atmosphere. Mirrors for most critical or scientific uses require the use of front-surface reflectors, with the reflecting coating on the exposed front surface of the

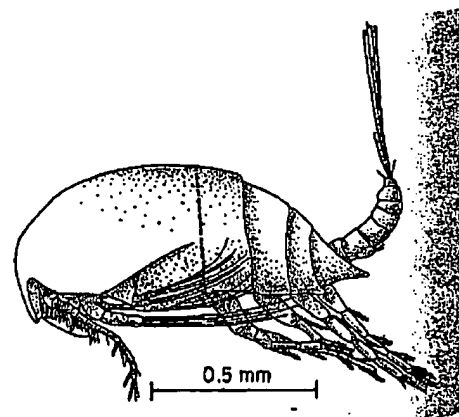
glass. In this case, a hard overcoat of a thin layer of silicon dioxide is frequently deposited over the metal to protect the delicate thin metal surface. The reflectivity of the mirror with respect to wavelength depends on the choice of the metal for the reflector and the material and thickness of material layers in the overcoat. In some cases, a fully dielectric stack will be used as a reflecting coating with special spectral selective properties to form a dichroic beam splitter, as in a color television camera, or as an infrared-transmitting "cold mirror" for a movie projector illumination system. *SEE REFLECTION OF ELECTROMAGNETIC RADIATION.*

R. R. Shannon

Misophrioida

A small but evolutionarily significant order of the subclass Copepoda, containing only a few species. First described in the nineteenth century, the misophrioids have, at one time or another, been assigned to all three of the major free-living copepod orders, Calanoida, Cyclopoida, and Harpacticoida. Their rank as a distinct taxon is now generally accepted.

Misophrioids have two subdivisions of the body, the anterior prosome and posterior urosome, articulated immediately behind the fifth thoracic somite. This feature immediately distinguishes misophrioids from calanoids. Like calanoids, some misophrioids have a dorsal heart, a character that distinguishes the taxon from both cyclopoids and harpacticoids. The misophrioids have four unique characteristics (see illus.): a carapacelike posterior extension of the head region (cephalosome) that encloses the first leg-bearing segment; the absence of the nauplius eye in all life stages; the retention of the antennary gland as the functional excretory system of adults; and a single naupliar developmental stage. In *Benthomisophria*, structures called cone organs occur on patches on both sides of the cephalosome, and are secretory, although the chemical composition of their secretion is not known. Since they can be swept over by the antennae and mandibular palps it has been proposed that secretion from the cone organs is spread by these appendages over the cephalosome to inhibit settlement of fouling organisms.



Lateral view of *Benthomisophria cornuta*. (After G. A. Boxshall, *The functional morphology of Benthomisophria pallata*, with a consideration of the evolution of the Misophrioida, Crustaceana, suppl. 7, 1984)